ENGINEERING STUDIES

STRUCTURAL RESEARCH SERIES NO. 20

STATIC TESTS OF BOLTED AND RIVETED JOINTS

By
DOUGLAS T. WRIGHT
and
W. H. MUNSE

UNIVERSITY OF ILLINOIS
URBANA, ILLINOIS

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A Progress Report
of an Investigation Conducted by
THE UNIVERSITY OF ILLINOIS ENGINEERING EXPERIMENT STATION

in Cooperation with
The Research Council on Riveted and Bolted Structural Joints
and
The Illinois Division of Highways

PROJECT IV

Urbana, Illinois
January 1952

STATIC TESTS OF BOLTED AND RIVETED JOINTS

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STATIC TESTS OF BOLTED AND RIVETED JOINTS

I. INTRODUCTION

1. Object and Scope of the Investigation

This report presents the results of a group of static tests of bolted and riveted structural joints. The general purpose of these tests and of a series of similar tests previously reported*(1) was to determine the significant characteristics of high tensile bolted lap-type joints subjected to static loading. A second previous report (2) presented the results of fatigue tests of high tensile bolted lap joints. Together, these two previous reports and the present one, covering one phase of a general study of bolted structural joints, give the results of an extensive program of tests on the static and fatigue strengths of bolted lap joints, fabricated with ~~high~~ tensile strength steel bolts.

The specific purpose of the static tests reported herein was to study three questions which arose as a result of the previous group of static tests. These are, (a) what is the amount of end distance required to prevent failure by tearing out at the ends, (b) what are the relative strengths of lap joints with two and three fasteners in line, and (c) what are the relative strengths of two fastener lap-type and butt-type joints?

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*(1) The numbers in parentheses refer to the references listed in the bibliography.

The last two questions were prompted by the "separating tendency" observed during the previous static tests and the possibility that this might have an adverse effect on the joint strength. (For an illustration of this "separating tendency" see Fig. 2, p. 16 of reference 1).

As in the previous tests the variables in these tests included faying surface condition, fastener type, bolt tension, and shear-ratio. (The shear-ratio is the ratio of fastener shear stress to plate net tensile stress).

2. Acknowledgments

The tests described in this report constitute a part of the work resulting from a cooperative agreement between the Engineering Experiment Station of the University of Illinois, the Research Council on Riveted and Bolted Structural Joints, and the Illinois Division of Highways.

This laboratory study, a part of the Structural Research program of the Department of Civil Engineering, is under the general direction of N. M. Newmark, Research Professor of Structural Engineering and W. H. Munse, Research Assistant Professor of Civil Engineering. The tests were made at the Arthur Newell Talbot Laboratory by Douglas T. Wright, assisted by F. W. Schutz, Jr., Research Assistants in Civil Engineering working under the direct supervision of Professor Munse.

The members of the Project IV Committee which planned the tests reported herein are as follows:

W. C. Stewart, Chairman, Industrial Fasteners Institute

Raymond Archibald, Bureau of Public Roads

Frank Baron, Northwestern University

John S. Davey, Russell, Burdsall and Ward, Bolt and Nut Company

R. A. Hechtman, University of Washington

T. R. Higgins, American Institute of Steel Construction

Jonathan Jones, Bethlehem Steel Company

J. J. Kelley, Pittsburgh Screw and Bolt Corporation

K. H. Lenzen, Purdue University

F. H. Lovell, Pennsylvania Railroad

Joseph Matte, Jr., Albert Kahn Associates, Architects and Engineers

W. H. Munse, University of Illinois

N. M. Newmark, University of Illinois

W. R. Penman, Bethlehem Steel Company

W. M. Wilson, University of Illinois

L. T. Wyly, Purdue University

II. DESCRIPTION OF THE SPECIMENS AND TESTS

3. Description of the Specimens

The dimensions and details of the test specimens are presented in Fig. 1 and Table 1.

The purpose of the Group I tests was to determine the end distance necessary to prevent failure by tearing out at the ends. Since this type of failure was encountered only in the S9 specimen of the preceding (1949) study, the specimens of Group I were made exactly as S9 except for the end distance. The end distances for specimens S10 and S11, as given in column 6 of Table 1, were 1 1/2 and 1 3/4., respectively. The end distance for S9 was 1 1/4 in.

The specimens of group II were similar also to the specimens of the preceding study, except that three fasteners were provided in line instead of two. By increasing the net plate width 50 per cent, it was possible to use the same plate thicknesses and tension - shear - bearing ratios as in the earlier tests, without changing other dimensions.

Group III was a series of twelve bolted, butt-type joints in which the strap plates were designed to be the critical component. These strap plates were made exactly the same as the plates of the bolted joints of the 1949 program. This resulted in a group of joints identical with those of the earlier study, except that the bolts were stressed in double shear rather than in single shear.

Groups II and III each contained three sets of joints having shear ratios of 0.75, 1.00 and 1.25. All the joints of Group I were designed to have a shear ratio of 1.25. Since the bearing stress was not intended to be a variable in this investigation, the bearing ratio, the ratio of bearing stress to tensile stress, was held constant at a value of approximately 1.35.

Each set of specimens in groups I and II contained four bolted joints of which two had bolt tensions of approximately 35,000 lb. and two had zero bolt tensions. The three sets of Group II had, in addition, two riveted joints each. One half of all the joints tested had lacquered faying surfaces: the other half had untreated dry mill-scale faying surfaces.

The fasteners, both bolts and rivets, were 7/8 in. in nominal diameter. The rivets were of ordinary structural grade steel (ASTM-A141) the bolts were high tensile strength steel bolts meeting ASTM - 325T designation (3), and the steel plate for the specimens was of ASTM, A-7 quality.

4. Description of Tests

The specimens were tested in a 200,000-lb. Riehle screw-type testing machine. The slip of the joints (relative movement between the plates) was measured at successively increasing loads by means of a pair of mechanical dial gages mounted on opposite edges of the specimens. This type of measurement does not give an exact measure of the slip at the fasteners in the joint but does give a relative measure which can be used to compare similar specimens and to give a general indication of the action of the joints.

For the two-fastener lap joints, the slip dials were mounted opposite a point halfway between the two fasteners, as shown in Fig. 2, p. 16 of reference 1. For the three-fastener lap joints, the slip dials were mounted opposite the center fastener. In both of these cases, changes in the dial readings indicated longitudinal movement of one plate with respect to the other.

On the two-fastener butt-type joints, as in the case of the two-fastener lap joints, the slip dials were mounted on brackets opposite a point halfway between the two fasteners. However, the brackets on the butt joints operated in such a manner that the dials indicated the average longitudinal slip of the two strap plates with respect to the center plate.

The bolt tension was determined by measuring the change in bolt length with the gage shown in Fig. 4, p. 10 of reference 4. For a tension of 35,000 lb., (which corresponds to a stress of 58,200 psi on the body of the bolt, and 76,000 psi on the "effective" mean area) the elongations required for the various grips were approximately as follows:

GRIP	ELONGATION
3/4 in.	0.0037 in.
1 in.	0.0042 in.
1 1/4 in.	0.0048 in.
1 5/8 in.	0.0055 in.
2 1/4 in.	0.0067 in.
2 3/4 in.	0.0077 in.

III. RESULTS OF TESTS

5. Results of Tests

The results of the tests on the 38 specimens of this study are presented in Table 2. For every specimen, the table gives the maximum load carried by the joint and the tensile, shear, and bearing stresses corresponding to this load. Column 4 of the table indicates, by the letters S and T, whether the joints failed in the fastener (shear) or in the plate (tension) respectively. The end-tearing type of failure observed in the previous tests was not encountered in these tests, nor was there any perceptible bulging out at the ends of the plates to indicate the start or tendency toward such a failure.

In every case of shear failure in the bolted joints, an appreciable necking down of the plates occurred by the time the bolts failed. In several cases, the plates had started to tear across their net section only to have the bolts shear before the plate failure could be completed (see Fig. 2a). This would seem to indicate that the bolted lap joints with a shear ratio of approximately 1.25 were very nearly of balanced design.

Although the fasteners in the butt joints of Group III were stressed in double shear, the bolts sheared off on one side only (see Figs. 2c and 2d). The reason for this appears to be that the 1/16-in. clearance in the bolt holes permitted the bolts to bend when failure occurred and thus to be pulled free on the side opposite to that on which the fractures occurred.

Joint S16-3 was exceptional in that it was the only one to suffer a shear failure of the twelve bolted joints with a shear ratio of unity that were tested in this and the preceding study. However, a plate tension failure (see Fig. 2c), had commenced before the bolt failed.

It should be noted that when the lacquered riveted joints of Group II were tested, the lacquer on the faying surfaces was found to be quite sticky, indicating that it may not have been allowed to dry completely before the joints were assembled.

6. Load-Slip Relations

Four variables were considered in this study of the effect of various factors on the load-slip relations of the joints. They are, (1) the condition of the faying surfaces, (2) the fastener type and its tension, (3) the joint type, and (4) the ratio of shear to tensile stresses in the joint. It was found that the first two have the most important effect on the load-slip relations. Accordingly, Figs. 3 and 4 present stress-slip curves for all the joints tested combined in such a manner that all the curves, for joints of the same type and having the same shear ratio, are on a single graph. This permits a study of the effects of surface condition and fastener type and tension, on the load-slip relations of the joints, with other variables eliminated.

Because the rivets filled the holes, the effect of faying surface condition on the load-slip relations for the riveted joints was very small (see Figs. 3c, 3d, 4a, curves for specimens 3 and 6). For the bolted joints, however, the effect of surface condition was more pronounced. With high (35,000 lb.) bolt tension and for any given load, the lacquered joints suffered more slip than did similar joints with dry mill scale faying surfaces. This difference was greatest early in the test when the joint with dry mill scale surfaces had a slip point (that point at which the slip increases rapidly with a slight increase in load) at a load almost twice as great as that for the lacquered joint. At higher loads and larger slips this difference diminished until the bolts came into bearing, after which the characteristics of the joints were identical. With zero bolt tension, the effect of surface condition on the load-slip characteristics was not nearly as regular nor as great. This was due, at least in part, to the fact that it was very difficult to place the bolted joints in the testing machine without having the plates move with respect to one another. Any relative movement between the plates of a joint, of course, affected the amount of slip required to bring the bolts into bearing; it is not until the bolts are in bearing that a joint with zero bolt tension can start to carry load. From the 8 sets of curves in Figs. 3 and 4, it can be seen that in three cases the joints with zero bolt tension with lacquered surfaces suffered less slip for a given load than did those with plain mill scale, surfaces (see Figs. 3a, 3d, 4a), in one case the opposite was true (see Fig. 4d), and in the other four cases there was little appreciable difference (see Figs. 3b, 3c, 4b, 4c).

With zero bolt tension, slip sufficient to bring the bolts into bearing occurred at a very low load level, and further "slip" was due to actual deformation of the material of the joint under load. With the bolts tightened so as to clamp the plates of the joint together, the joints carried an appreciable load with little or no slip by means of friction alone. When this frictional resistance was overcome (the slip point) the joints slipped with only a slight increase in load until the bolts were in bearing. After the bolts came into bearing, further "slip" occurred along a load-deformation curve similar to that followed by the joints with zero bolt tension.

A comparison between the riveted joints and the bolted joints with high bolt tension is of significance since the shear deformation curves are different for rivets and bolts, and have a pronounced effect on the load-slip characteristics of the joints.

For the joints of Series S12 (shear ratio = 0.75), (see Fig. 3c), the riveted joints carried more load for a given slip than did the bolted joints--with but one exception: the bolted joint with mill scale surfaces and a high bolt tension had a frictional resistance that permitted it to carry, without slip, a stress of 25,000 psi while at this same stress the riveted joints had already slipped almost 0.010 in.

For the joints of Series S13 (shear ratio = 1.0), (see Fig. 3d), the riveted joints carried more load for a given slip than did the bolted joints, up to the point where the rivet shear deformation curves had become nearly horizontal and were crossed by the still rising shear deformation curves of the bolts. Up to the point where the frictional capacity of the bolted joints was reached, the curves for the bolted and riveted joints of this Series were little different.

For the joints of Series S14 (shear ratio = 1.25), (see Fig. 4c), the riveted specimens again carried more load for a given slip than did the bolted specimens with the same faying surface finish, up to the point where the shear deformation curves cross when the rivet deformation curves become nearly horizontal. However, for this set of curves, the differences are smaller than for the curves of Series S13. For the bolted joint with no lacquer on its faying surfaces, the load at which the slip point was reached was almost as great as the load at which the rivet started yielding in shear. Another factor tending to reduce the differences between these curves is that the deformation curves intersect at a smaller slip than for Series S13.

The effects of joint type and shear ratio on load-slip relations were, in general, not nearly as well defined nor as significant as the effects of surface condition and fastener type and tension. This is readily evident in comparisons of Figs. 3 and 4.

IV. ANALYSES OF TEST RESULTS

7. Influence of Shear Ratio on the Strength of the Joints

For the riveted joints, the same well-defined variation of ultimate strength and fracture mode with the shearing ratio was found for these tests as was found in the previous study [1]. With a shear ratio of 0.75, all joints failed in the plates, whereas with a shear ratio of 1.00 or 1.25 all joints failed by shearing the rivets. The riveted joints with a shear ratio of unity developed an average shear stress of 58,600 psi and those with a shear ratio of 1.25 developed an average shear stress of 58,100 psi.

In the tests of the bolted joints, no such regular variation of fracture mode with shear ratio was observed. No bolt shear failures were obtained in the eight tests of joints with a shear ratio of 0.75; one shear failure was obtained in the eight tests of joints with a shear ration of unity, and ten shear failures were obtained in the sixteen tests of joints with a shear ratio of 1.25. On this basis the critical shear ratio appears to be near 1.25 although the scatter of the results just described indicates that it would be difficult, if not impossible, to determine it more exactly without a number of additional studies. The fact that the critical shear ratio for bolted lap joints is very close to 1.25 is further borne out by the results presented in Table 3. The maximum tensile stresses carried by the joints that failed in shear were not appreciably different from the maximum tensile stresses carried by the joints that failed in tension. In other words, the maximum load-carrying capacity of bolted lap joints with a shear ratio of 1.25 was practically independent of whether the joint failed in tension or shear.

The critical shear ratio for bolted butt-type joints was found to slightly less than 1.25. This was indicated by the fact that, although all butt-type bolted joints with a shear ratio of 1.25 failed in shear, the maximum tensile stresses carried by the joints failing in shear were only a little less than the tensile stresses carried by butt-type joints failing in tension. (See Table 3).

8. Influence of Plate Surface Conditions and Bolt Tension on the Strength of the Joints

An examination of Table 4 shows most conclusively that neither the fastener tension nor the condition of the faying surfaces had any appreciable effect on the ultimate joint strength of either the riveted or bolted joints. In this connection it is interesting to note that surface conditions and bolt tension were the most important variables with respect to load-slip relations, yet they had little or no effect on joint ultimate strength.

9. Influence of End Distance of Bolt Holes on the Strength of the Joints

In the previous tests of bolted joints [1], it was found that a combination of a shearing ratio of 1.25, an end distance of 1 1/4 in.

and a bolt diameter of 7/8 in. resulted in tearing out the ends of the plates. The results from Series S10 and S11 of the study reported herein show that an end distance of 1 1/2 in. is sufficient to prevent tearing failures in two-fastener lap joints with 7/8 in. bolts and a shear ratio of 1.25.

This result applies only to one bolt diameter and one shear ratio. However, it may be possible to amplify the significance of the results obtained experimentally without making further tests.

The AISC specification gives a limit for minimum end distance for riveted joints which may be adapted to these bolted joints by a slight modification. The minimum end distance prescribed by the AISC specification to prevent end failures in riveted joints (Shear ratio = 0.75) is as follows: "The distance from the center of any rivet under computed stress, and that end or other boundary of the connected members toward which the pressure of the rivet is directed, shall be not less than the shearing area of the rivet shank divided by the plate thickness."

If it is assumed that the safe end distance is proportional to the ratio of shear stress to tensile stress for balanced design, a rule for bolted joints corresponding to the AISC rule quoted above, is as follows:

$$\text{Safe end distance} = \frac{4}{3} \; \frac{SA_s}{t}$$

where

S = the shear ratio for balanced design

A_s = the total shear area of the fastener, in sq. in.

t = the plate thickness in in.

The result obtained by substituting in this formula verifies this relationship. Substituting S = 1.25 (given on page 12 as the approximate value for balanced design), A_s = 0.60 sq. in., and t = 5/8 in., we obtain from the formula a value for safe end distance of 1.60 in. In the tests, an end distance of 1 1/2 in. was adequate, thereby suggesting that the above formula may be somewhat conservative.

10. Influence of Joint Type on Joint Strength

A comparison of two-fastener lap joints, three-fastener lap joints, and two-fastener butt joints has been made to determine whether or not the "separating" tendency noted in the previous lap-joint studies had any effect on the ultimate strength of the joints.

The two-fastener lap joints developed a greater ultimate tensile strength than did either of the other two joint types, and the three-fastener lap joints developed ultimate tensile strengths that were slightly larger than those developed by the butt joints. However, the differences, though reasonably consistent, never exceeded 7 per cent.

In this and the previous report [1] on bolted lap joints, it was observed that the lap joints deformed into a flattened S-shape, in an attempt to align the axes of the two plates. The effect of this deformation is to rotate the direction of principal stress with respect to the original axis of the joint, and accordingly, the areas resisting the principal stresses are greater (by a factor secant α, where α is the angle of rotation of the joint) than the areas usually computed to resist load. An examination of the bolts from the joints which suffered shear failures illustrates the effect: bolts from the butt joints had failure planes at right angles to the bolt axis whereas bolts from the lap joints had failure planes that deviated from the perpendicular by angles greater than the angle of rotation of the joint (see Figs. 2a, 2c and 2d).

There are two possible factors, either or both of which may have caused the difference between the results of the tests of the two- and three-fastener lap joints. First, a lap joint with three fasteners in line does not rotate as much as one with only two in line, and second, the three-fastener lap joint had wider plates than did the two-fastener lap joint, yet had the same hole diameter (see Figs. 2a and 2b).

It should be noted that, for all the bolted joints of this study, as originally designed, one shear plane in every joint crossed the bolts at a place where the shank was threaded (see Figs. 2a and 2c). This was a direct result of using the Research Council specification,[3] for the assembly of structural joints using high tensile steel bolts, to determine the bolt lengths. This specification requires, for 7/8 in. bolts, a bolt length 1 1/2 in. longer than the total grip to outside of washers with 2 in. of threaded shank.

After noting the single shear failures which occurred in Series S16 and the first two tests in Series S17, it was decided to test the last two specimens of Series S17 with bolts having a longer length of unthreaded shank than suggested by the specification. An examination of the specimens after fracture, particularly the sheared bolts, showed that a much better balance of load distribution was obtained in these last two joints. The bolts of these two specimens, S17-3 and S17-4, exhibited a phenomenon that was not observed for <u>any</u> of the bolts from the three other butt joints that failed in shear: the bolts had suffered large shear deformations on <u>both</u> shear planes (see Figs. 2c and 2d).

11. Summary of Results

The results of the tests described in this report may be summarized as follows:

1. For joints with 7/8 in. bolts and having a shear ratio of 1.25, an end distance of 1 1/2 in. was found to be sufficient to prevent end-tearing failures.
2. The two-fastener lap joints developed a greater ultimate tensile strength than did either the three-fastener lap joints or the two-fastener butt joints; and the three-fastener lap joints developed ultimate tensile strengths that were slightly larger than those developed by the butt joints.
3. Load-slip relations were affected principally by faying surface condition and fastener type and tension: joint type and shear ratio had only secondary effects on the load slip relations.
4. The effect of faying surface condition on load slip relations for riveted joints was much less pronounced than its effect for bolted joints.
5. With a high bolt tension, for any given load, joints with lacquered surfaces exhibited greater slip than joints with dry mill scale surfaces. The proportional difference was much greater earlier in the test, at working load levels, than at later stages of the test.

6. Neither the bolt tension nor faying surface condition had any appreciable effect on the ultimate strength of either riveted or bolted joints.

7. When slip, sufficient to bring the bolts into bearing, had occurred, further "slip" was due to actual deformation of the material under load. In this advanced stage of loading all joints had basically similar load-slip characteristics with slight differences resulting from different shear ratios.

8. With a shear ratio of approximately 0.75, all riveted joints suffered tension failures: with shear ratios of 1.0 and 1.25 all riveted joints suffered shear failures.

9. With a shear ratio of approximately 0.75 no bolted joints suffered shear failure, with a shear ratio of 1.0, one joint out of eight had a shear failure, and with a shear ratio of 1.25 ten joints our of 16 had shear failures. On the basis of these results, a balance between the ultimate shear strength and tensile strength for bolted joints appears to be at a shear ratio of nearly 1.25.

10. When the bolt dimensions were as recommended by the Research Council specifications [3] bolt shear failures always occurred through the threaded shank.

12. Bibliography

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2. Progress report, "Static and Fatigue Tests of Bolted Structural Lap Joints" by W. H. Munse, F. W. Schutz and H. L. Cox, Urbana, Illinois, July 1950.

3. "Specifications for Assembly of Structural Joints Using High Tensile Steel Bolts" approved by Research Council on Riveted and Bolted Structural Joints of the Engineering Foundation, Chicago, Illinois, January 31, 1951.

4. Progress report, "Calibration Tests of High Strength Bolts" by Douglas T. Wright and W. H. Munse, Urbana, Illinois, January 1951.

TABLE I

DESCRIPTION OF TEST SPECIMENS

Group No. (1)	Joint Type (2)	Spec. No. (3)	PLATE THICKNESS t in. (4)	PLATE THICKNESS t_s in. (5)	End Distance in. (6)	Faying Surfaces* (7)	Bolt Tension lb. (8)	Shearing Ratio (9)
I	Lap	S10-1	5/8	—	1 1/2	M.S.	0	1.25
		S10-2				M.S.	35,000	
		S10-3				Lq.	0	
		S10-4				Lq.	35,000	
		S11-1	5/8	—	1 3/4	M.S.	0	1.25
		S11-2				M.S.	35,000	
		S11-3				Lq.	0	
		S11-4				Lq.	35,000	
II	Lap	S12-1	3/8	—	2	M.S.	0	0.75
		S12-2				M.S.	35,000	
		S12-3				M.S.	Riveted	
		S12-4				Lq.	0	
		S12-5				Lq.	35,000	
		S12-6				Lq.	Riveted	
		S13-1	1/2	—	1 1/2	M.S.	0	1.0
		S13-2				M.S.	35,000	
		S13-3				M.S.	Riveted	
		S13-4				Lq.	0	
		S13-5				Lq.	35,000	
		S13-6				Lq.	Riveted	
		S14-1	5/8	—	1	M.S.	0	1.25
		S14-2				M.S.	35,000	
		S14-3				M.S.	Riveted	
		S14-4				Lq.	0	
		S14-5				Lq.	35,000	
		S14-6				Lq.	Riveted	
III	Butt	S15-1	3/8	7/8	2	M.S.	0	0.75
		S15-2				M.S.	35,000	
		S15-3				Lq.	0	
		S15-4				Lq.	35,000	
		S16-1	1/2	1 1/4	1 1/2	M.S.	0	1.0
		S16-2				M.S.	35,000	
		S16-3				Lq.	0	
		S16-4				Lq.	35,000	
		S17-1	5/8	1 1/2	1 1/2	M.S.	0	1.25
		S17-2				M.S.	35,000	
		S17-3				Lq.	0	
		S17-4				Lq.	35,000	

* M.S. indicates mill scale surfaces.
Lq. indicates lacquered surfaces.

TABLE 2

RESULTS OF TESTS

Group No. (1)	Spec. No. (2)	Shearing Ratio (3)	Failure Type* (4)	Ultimate Load lb. (5)	Stresses at Ultimate Load: Tension psi (6)	Shear psi (7)	Bearing psi (8)
I	S10-1	1.25	S	101,000	67,200	84,000	92,100
	S10-2	1.25	S	103,500	68,800	86,000	94,300
	S10-3	1.25	S	102,800	68,100	85,100	93,300
	S10-4	1.25	S	102,600	67,900	84,900	93,000
	S11-1	1.25	S	102,400	67,800	84,800	92,900
	S11-2	1.25	T	102,000	67,600	84,500	92,600
	S11-3	1.25	S	98,400	65,200	81,500	89,300
	S11-4	1.25	T	102,300	67,800	84,800	92,900
II	S12-1	0.75	T	85,300	63,100	47,300	85,200
	S12-2	0.74	T	85,900	64,200	47,500	86,000
	S12-3	0.75	T	82,500	61,200	45,900	82,600
	S12-4	0.74	T	85,100	63,600	47,100	85,200
	S12-5	0.74	T	85,800	63,900	47,300	86,300
	S12-6	0.75	T	84,800	62,900	47,200	84,900
	S13-1	0.99	T	118,600	66,400	65,700	90,300
	S13-2	0.99	T	118,300	65,800	65,100	89,500
	S13-3	1.00	S	103,400	57,200	57,200	78,400
	S13-4	0.98	T	118,200	66,400	65,100	90,300
	S13-5	1.00	T	120,800	67,000	67,000	91,100
	S13-6	0.99	S	108,700	60,600	60,000	82,400
	S14-1	1.23	T	149,500	67,200	82,700	90,700
	S14-2	1.23	T	144,100	64,600	79,500	87,900
	S14-3	1.24	S	103,100	46,100	57,200	62,700
	S14-4	1.23	T	152,400	68,300	84,000	92,900
	S14-5	1.24	T	152,200	68,100	84,400	92,600
	S14-6	1.24	S	106,500	47,600	59,000	64,700
III	S15-1	0.75	T	117,800	65,100	48,800	89,200
	S15-2	0.76	T	120,300	66,000	50,200	90,400
	S15-3	0.75	T	116,600	64,300	48,200	87,400
	S15-4	0.75	T	118,400	65,200	48,900	89,300
	S16-1	0.99	T	154,700	65,100	64,400	89,200
	S16-2	0.99	T	155,900	65,500	64,800	89,700
	S16-3	0.99	S	151,800	63,800	63,200	87,400
	S16-4	0.99	T	155,000	65,100	64,400	89,200
	S17-1	1.25	S	179,500	59,700	74,600	81,800
	S17-2	1.25	S	197,000	65,400	81,800	89,600
	S17-3	1.25	S	194,700	64,800	81,000	88,800
	S17-4	1.24	S	198,900	66,300	82,200	90,800

* S indicates a shear (fastener) failure.
T indicates a tension (plate) failure.

TABLE 3

SUMMARY OF TEST RESULTS FOR
BOLTED JOINTS

Series	Joint Description			Ultimate Shear Stress for Shear Failures psi	Ultimate Tensile Stress for Shear Failures psi	Ultimate Tensile Stress for Tensile Failures psi
	S/T Ratio	Joint Type	Number of Bolts			
(1)	(2)	(3)	(4)	(5)	(6)	(7)
S10	1.25	Lap	2	85,000	68,000	---
S11	1.25	Lap	2	83,200	66,500	67,700
S12	0.75	Lap	3	---	---	63,700
S13	1.00	Lap	3	---	---	66,400
S14	1.25	Lap	3	---	---	67,000
S15	0.75	Butt	2	---	---	65,200
S16	1.00	Butt	2	63,200	63,800	65,200
S17	1.25	Butt	2	79,900	64,000	---

TABLE 4

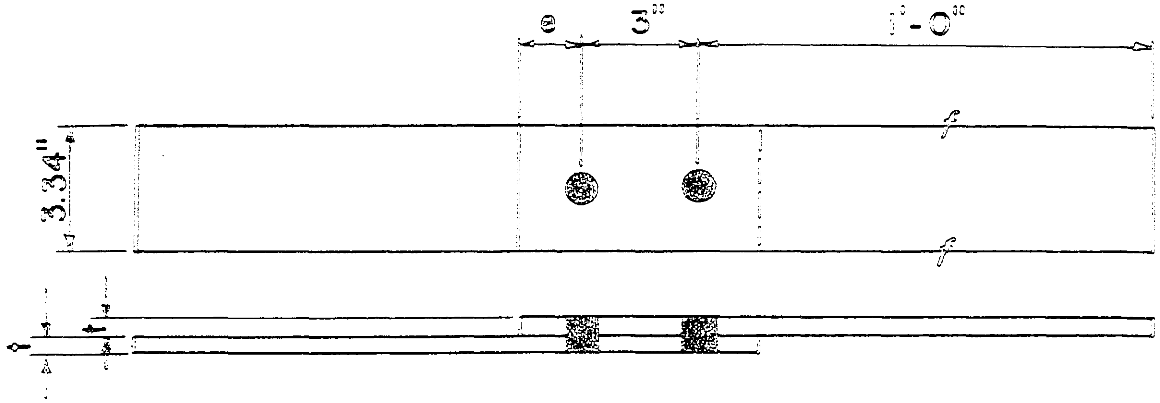
SUMMARY OF PLATE AND FASTENER

STRESSES AT ULTIMATE LOAD

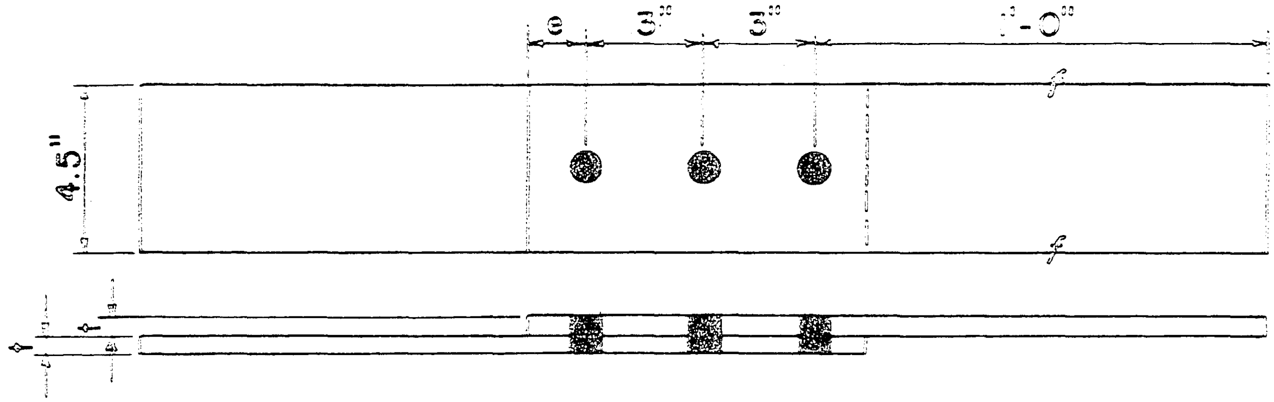
Bolt Tension (Kips)	Faying* Surface	Ultimate Stresses at Shear-Tension Ratios of 0.75		1.00		1.25	
		Plate Failure	Fastener Failure	Plate Failure	Fastener Failure	Plate Failure	Fastener Failure
				Bolted Joints			
0	M.S.	64100	—	65800	—	67200	81100
0	Lq	64000	—	66400	63200	68300	82500
35	M.S.	65100	—	65600	—	66100	83900
35	Lq	64600	—	66000	—	68000	83600
Average		64400	—	65900	63200	67300	82600
				Riveted Joints			
	M.S.	61200	—	—	57200	—	57200
	Lq	62900	—	—	60000	—	59000
Average		62000	—	—	58600	—	58100

* M.S. indicates Mill Scale surfaces.

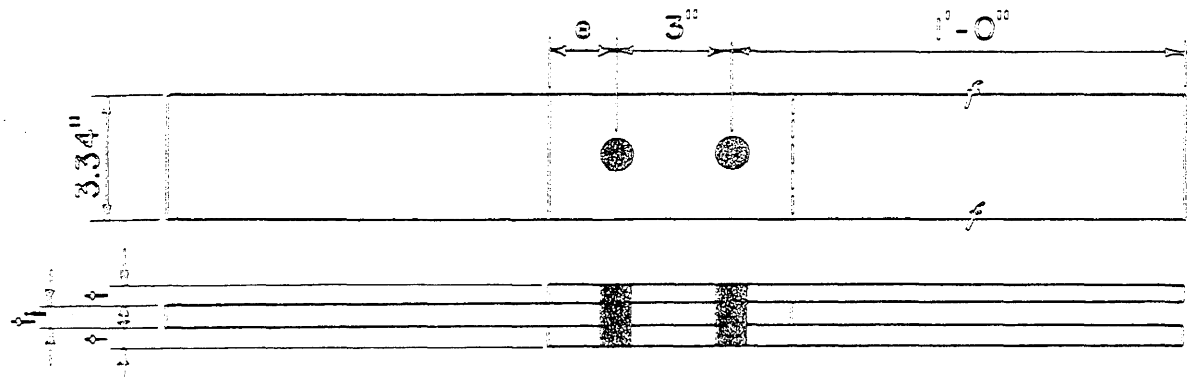
Lq. indicates Lacquered surfaces.



S-10 & S-11



S-12, S-13, & S-14



S-15, S-16, & S-17

FIG. 1 DETAILS OF THE SPECIMENS

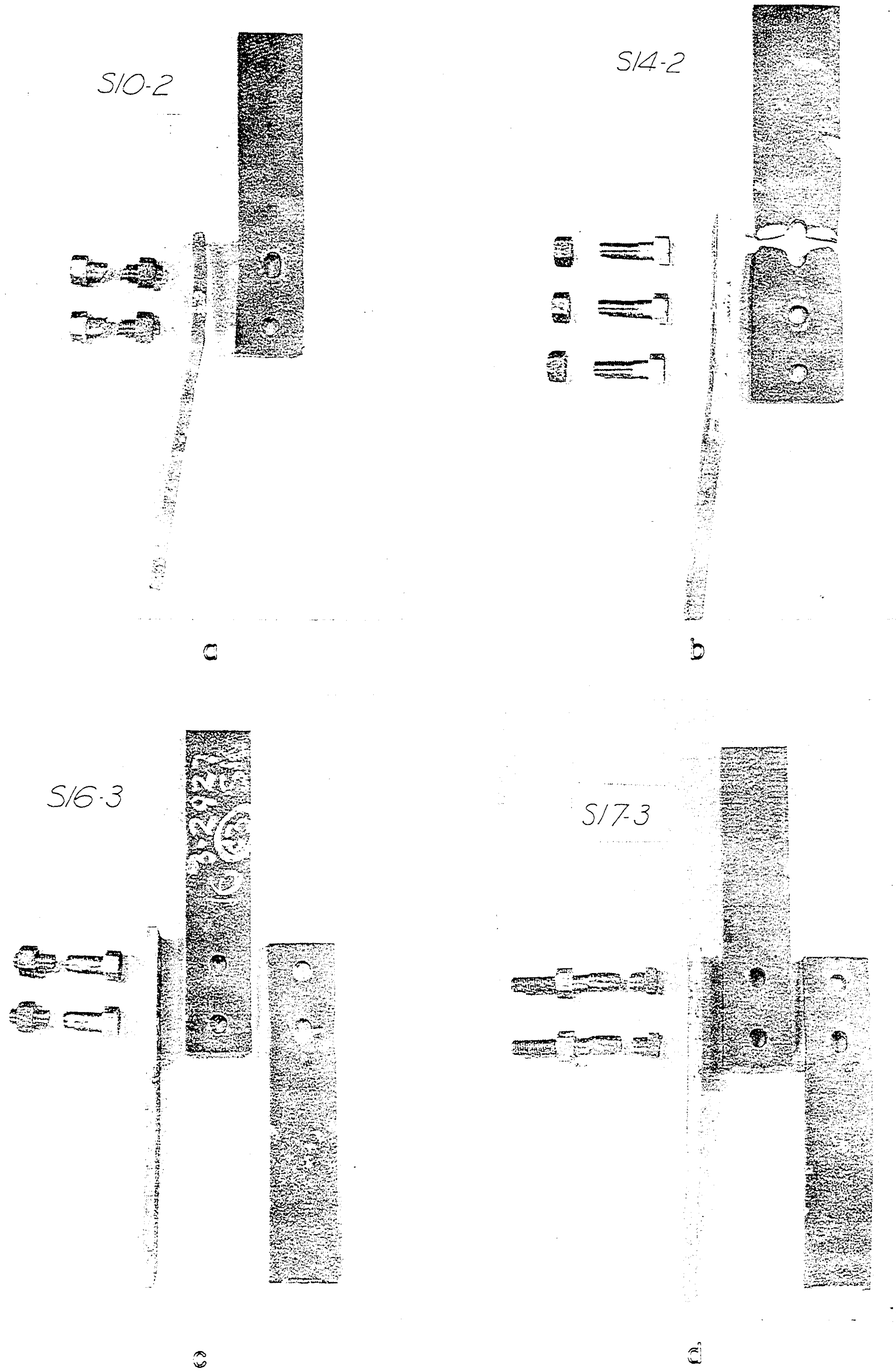


FIG. 2 TYPICAL SPECIMENS AFTER FAILURE

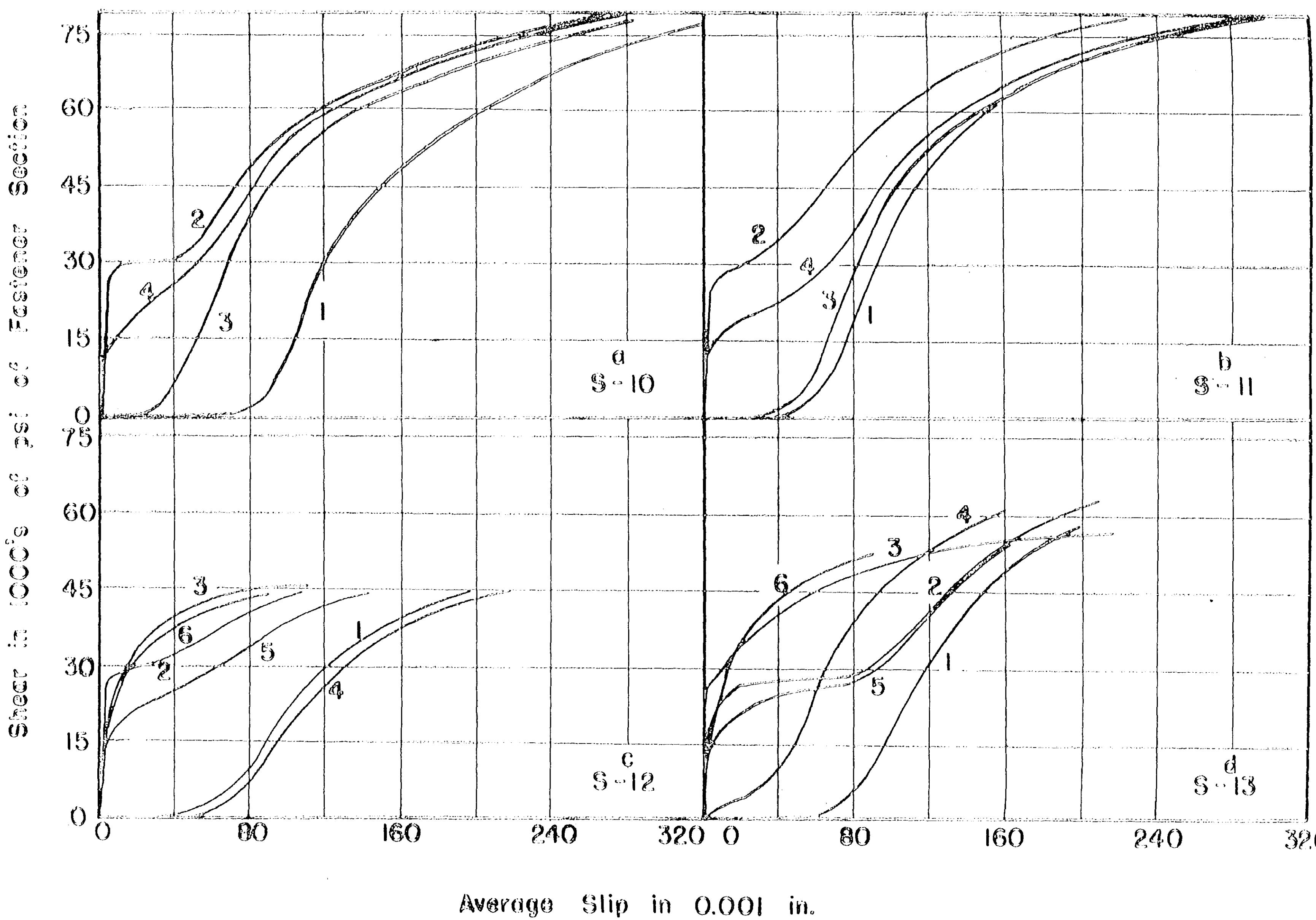


FIG. 3 LOAD-SLIP RELATION FOR JOINTS S-10 TO S-13

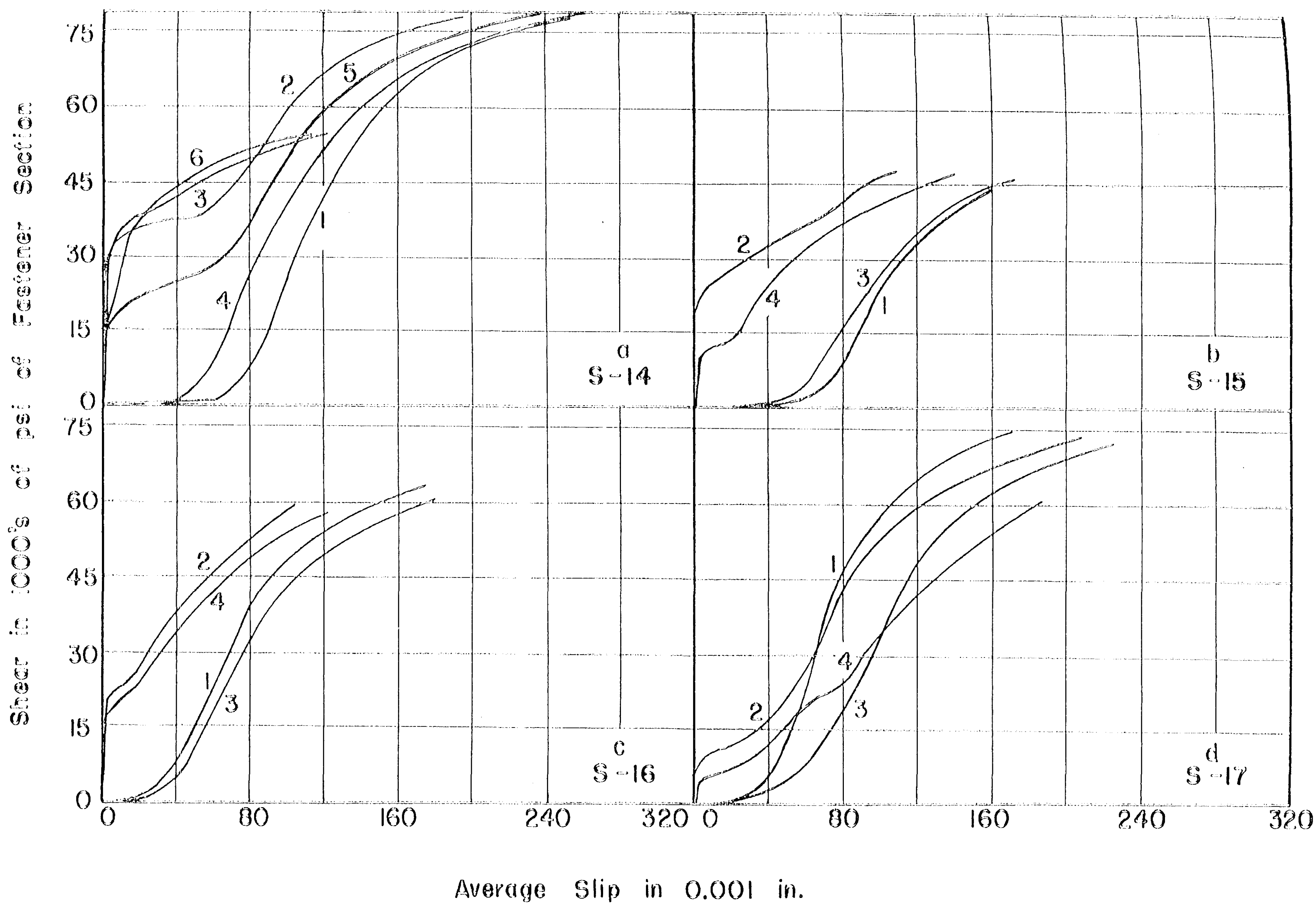


FIG. 4 LOAD-SLIP RELATION FOR JOINTS S-14 TO S-17